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(71) Applicant(s)
Siemens Aktiengesellschaft
(Incorporated in the Federal Republic of Germany)
Wittelsbacherplatz 2, D-80333 München,
Federal Republic of Germany

(72) Inventor(s)
Leo Rademacher

(74) Agent and/or Address for Service
Derek Allen
Siemens Group Services Limited, Intellectual Property Department, Siemens House, Oldbury, BRACKNELL, Berkshire, RG12 8FZ, United Kingdom

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(54) Abstract Title
**A data detector comprising a channel estimator, an equaliser, and a data regenerator, with feedback**

(57) A data detector comprises a channel estimator 54, which estimates the impulse response of the communication channel, an equaliser 52, which receives signal samples and generates data decisions $SD_{t,i}$ and error signals $e_{t,i}$ from them in combination with channel impulse estimates from the estimator 54, both the data decisions $SD_{t,i}$ and error signals $e_{t,i}$ being fedback to the estimator 54 to allow it to adapt its estimated channel response, the data decisions $SD_{t,i}$ also being fed to a data regenerator 56, which generates a sequence of feedback metrics which are fed back to the equaliser 52. The invention mitigates intersymbol interference and finds application in TDMA systems such as the GSM system, as well as future mobile radio systems such as W-CDMA and TD/CDMA.

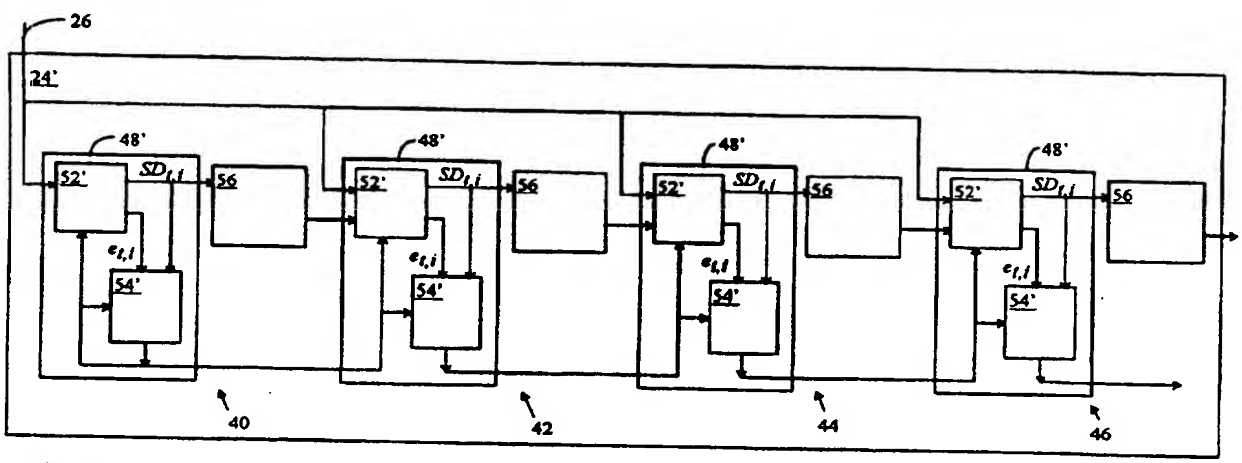


Fig. 4

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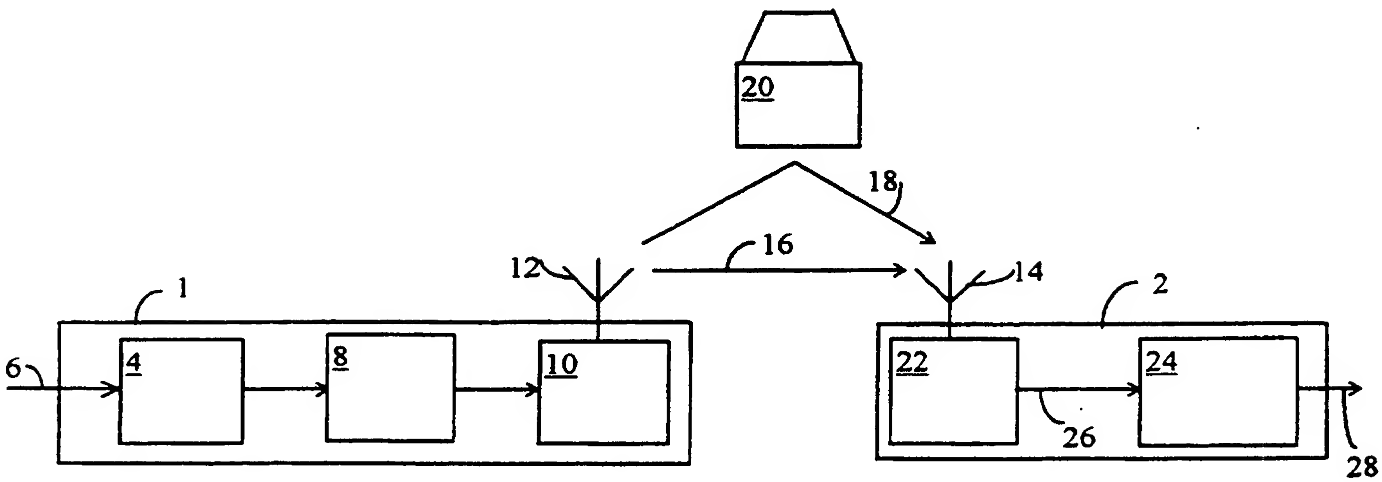


Fig. 1

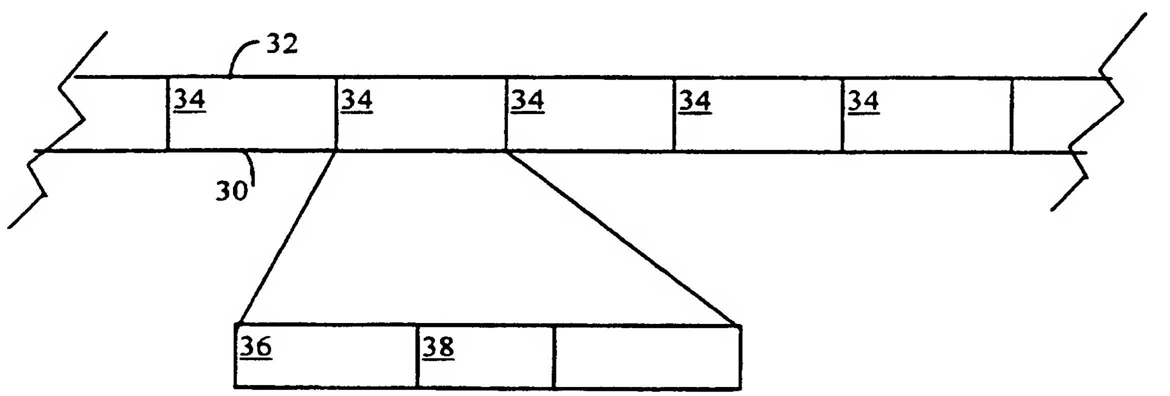


Fig. 2

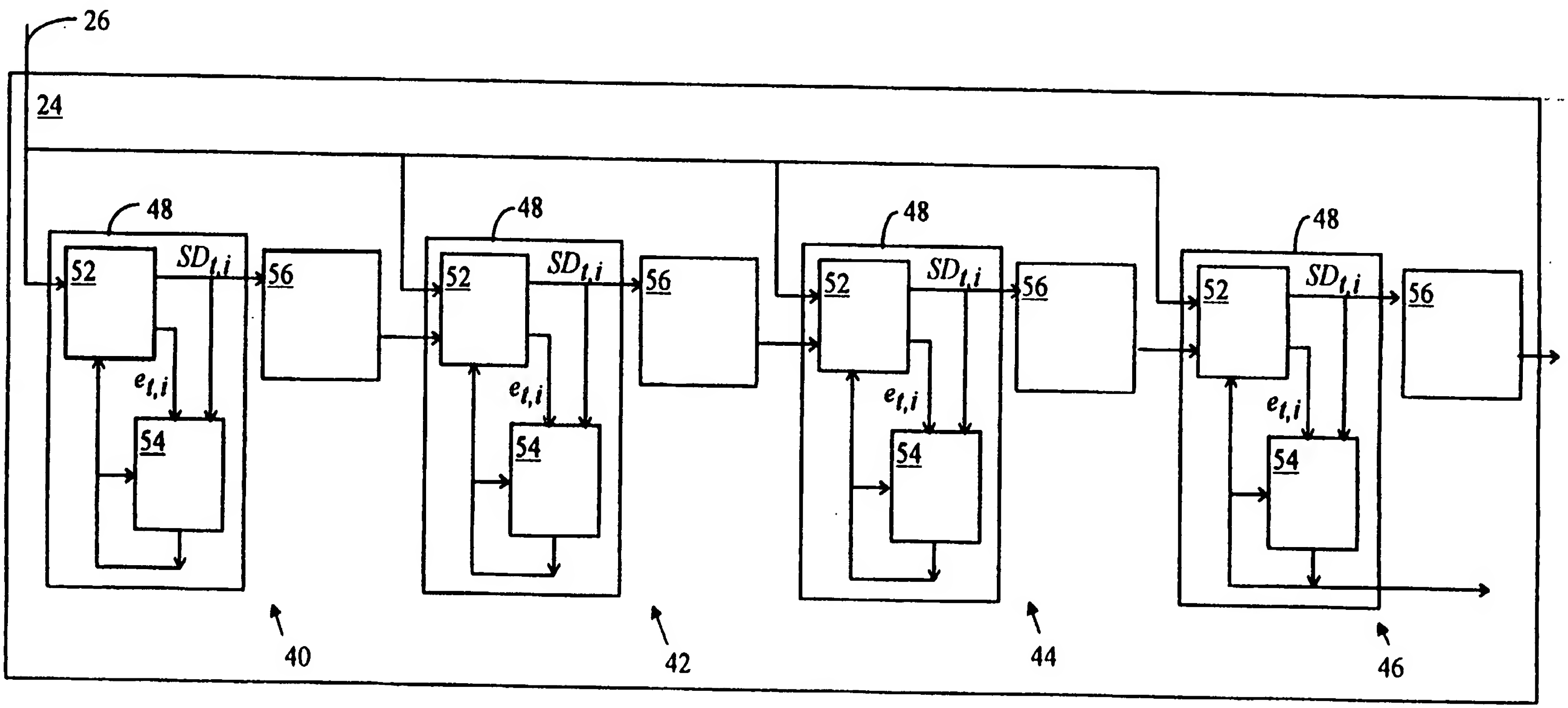


Fig. 3

98E2557
98 P 2428

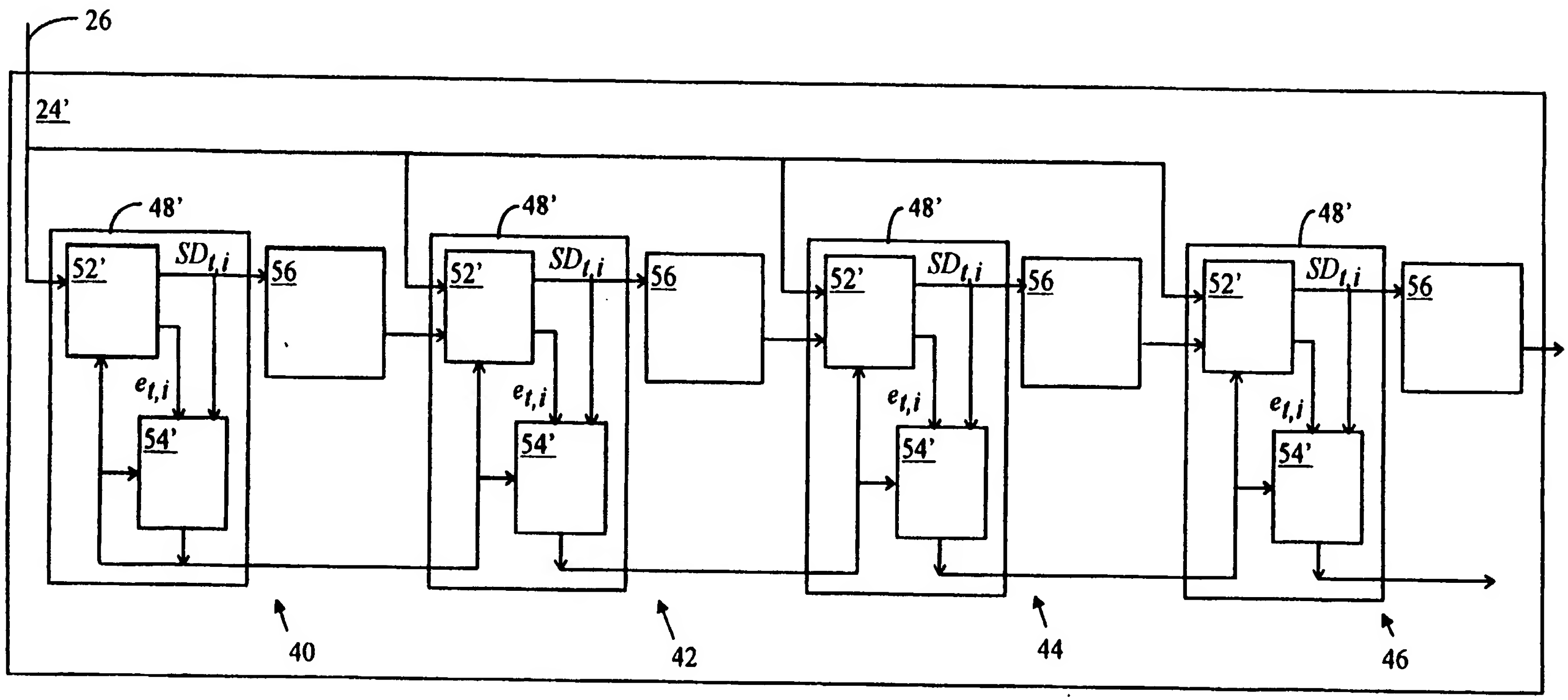




Fig. 4

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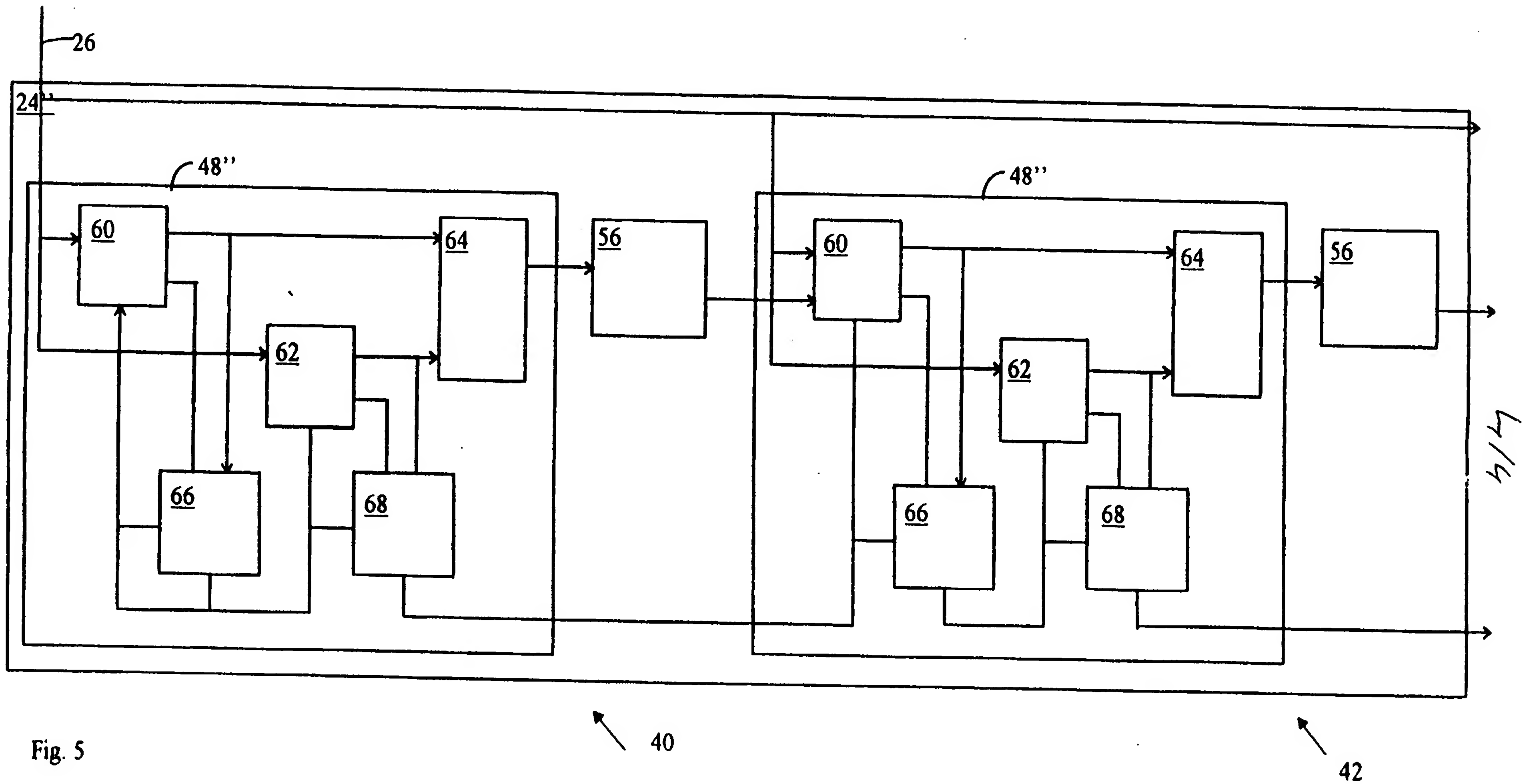


Fig. 5

Description of Invention

Data detector and method of detecting data from a sequence of received signal samples

The present invention relates to data detectors which operate to generate an estimate of a data sequence from a sequence of received signal samples representative of the data sequence. Furthermore the present invention relates to methods of detecting data represented as a sequence of received signal samples. The present invention also relates to radio communications receivers which operate to recover data from radio signals representative of the data.

Data is communicated using digital communication systems by representing the data as electrical signals and communicating the signals from a transmitter to a receiver. At the receiver the data is recovered from the communicated electrical signals. However in many fields of digital communications, the electrical signals are corrupted during transmission between the transmitter and the receiver by naturally occurring phenomena or characteristics of the communications system itself. An example of such a digital communications system is a radio communications system which operates to communicate digital data by representing the data as radio signals and transmitting the radio signals to a receiver. More particularly in the field of mobile radio telecommunications, a frequency at which the radio signals are communicated, results in corruption of the radio signals via multi-path propagation, fading effects and noise. As such, known radio communication systems include equalisers which operate to mitigate the effects of inter symbol interference and to recover the data from the radio signals in spite of the multi-path, the fading and the noise. Furthermore the digital data is often encoded using an error correction code to the effect that a decoder operating in combination with the equaliser in the receiver, can correct

errors in the digital data sequence recovered by the equaliser.

A known data detector in which an equaliser and a data decoder operate in combination to improve the integrity of the data recovered from received signals, is described in a publication entitled 'Iterative correction of intersymbol interference; turbo equalization' by C. Douillard, M. Jezequel, C. Berrou, A. Picart, P. Didier, A. Glavieux, published in the ETT Journal, volume 6, No. 5, September-October 1995. This publication discloses a method known to those skilled in the art as 'turbo' equalisation, in which an equaliser generates soft decision metrics representative of a probability that a data sequence recovered by the equaliser is correct. The soft decision metrics are fed to a subsequent decoder which uses the *a priori* decision metrics to generate a further sequence of soft decision metrics which are fed back to the equaliser for a further iterative estimate of the data with the effect that a plurality of iterations results in a substantial improvement in the integrity of the detected data sequence.

The term soft decision metric is known to those skilled in the art as being a weight or measure associated with the likelihood of a particular data symbol recovered by a decoder or an equaliser being correct.

The turbo equalisation technique disclosed in the above mentioned publication by Douillard et al, provides a technique whereby a substantial improvement of the integrity of the detected data may be effected and is particularly appropriate for radio communications systems.

A further naturally occurring disturbance to communicated signals in some digital communication systems is known as time dispersion or Doppler shift. This disturbance occurs, for example, in mobile radio communication systems in which

the transmitter and receiver move with respect to one another whilst the radio signals are being transmitted. As a result, a channel impulse response of the communications channel through which the communications signals pass changes with respect to time.

For some digital communication systems such as mobile radio communications systems which operate in accordance with time division multiple access, the effect of time dispersion is to reduce the integrity of data which an equaliser operating to recover the transmitted data can obtain. With time division multiple access radio communications systems, a radio frequency carrier signal is divided in time, into a plurality of time slots. Data is communicated using bursts of radio signals transmitted in the time slots. A result of the time dispersion caused by Doppler shift, is that the impulse response of the radio communications channel through which the radio signals pass, changes with respect to time, with the effect that the channel impulse response is different in one part of the burst, than in another part of the burst of radio signals.

In order to obviate the effects of time dispersion, it is known to include within the receiver, means for adapting the channel impulse response estimate in accordance with a relative time at which the radio signals are communicated. However, it remains a technical problem to adapt a channel impulse response with respect to a time at which the radio signals are communicated in a receiver which operates to effect turbo equalisation. This technical problem is addressed by the data detector and method of detecting data according to the present invention.

The technical problem is addressed generally by arranging for a channel impulse response to be adapted in accordance with a temporal position of data symbols being detected by an equaliser from the received signal samples in combination

with the adapted channel impulse response, and using the adapted channel impulse response in a subsequent iteration of the turbo detection of the data.

According to the present invention there is provided a data detector which operates to generate an estimate of a data sequence from a sequence of received signal samples, said data detector comprising

- a channel estimator means which operates to generate an estimate of an impulse response of a communications channel through which the received signals have passed,
- an equaliser means coupled to said channel estimator means which operates to generate a sequence of data decisions and error signals from said sequence of signal samples in combination with adapted versions of said channel impulse response estimate, said channel impulse response estimate being adapted by said estimator means in accordance with said error signals and said data decisions, and
- a data regenerator means which operates to process said sequence of data decisions and to generate therefrom a sequence of feed back metrics which are fed back to said equaliser, said equaliser further operating to generate a subsequent sequence of data decisions from said feed back metrics in combination with said sequence of signal samples, which subsequent data decisions are to said data regenerator which operates to generate said estimate of said data from said subsequent data decisions, wherein each of said updated versions of said channel impulse response estimate is used to generate said subsequent sequence of data decisions.

It is known to adapt a channel impulse response estimate used in an equaliser to recover data from received signal samples in accordance with a temporal displacement of the received signals. However by arranging for the adapted channel impulse response in a first iteration of a turbo detection process to be fed to a subsequent stage in the iterative process, the channel estimate used in the subsequent stage will be based

on a more accurate estimate of the channel impulse response which has already been adapted in the first stage and therefore provides a better estimate for use in the equaliser of the subsequent stage.

Advantageously, the adapted versions of the channel impulse response estimate are used by the equaliser to generate the subsequent data decisions, to the effect that a temporal correspondence is arranged between the signal samples and the adapted version of the channel impulse response used to make each data decision.

The channel estimator operates to adapt the channel impulse response estimate from the error signals and the detected data decisions. Thus, in an arrangement where the adapted channel impulse response is used by the equaliser to make the data decisions, as is the case for the first iteration of the turbo detection process, there is always a delay or lag between an update of the channel impulse response, and the detection of the data. However by using the adapted versions of the channel impulse response estimate in a subsequent iteration of the turbo detection, and arranging for the adapted versions of the channel impulse response to be in temporal correspondence with the detected data decisions generated by the equaliser, the delay or lag between the generation of the data decisions and the channel impulse response is substantially alleviated.

Advantageously the data regenerator means operates to generate a plurality of sequences of feed back metrics which are fed to the equaliser which generates a corresponding plurality of sequences of data decisions and error signals, the plurality of sequences of data decisions being used by the data regenerator to form the plurality of feed back metrics and the error signals being used to update the channel impulse response estimate for each of the plurality of sequences of data decisions generated by the equaliser.

Furthermore each of the updated versions of the channel impulse response estimates may be used to form a subsequent one of the sequences of data decisions.

The equaliser means may be a plurality of equaliser means the channel estimator may be a plurality of channel estimator means and the data regenerator means may be a plurality of regenerator means, the plurality of equaliser means, channel estimator means, and data regenerator means may be coupled in operative association to form a corresponding plurality of stages, each of which stages operates to generate one of the plurality of sequences of data decisions, one of the plurality of feed back metrics and one of the versions of the channel impulse response estimates, the versions of the channel impulse response estimate from one stage being fed to the channel impulse response estimate of a subsequent stage.

As will be appreciated by those skilled in the art, the turbo equalisation process may be arranged to be effected by a plurality of stages, each stage having an equaliser and a data decoder. Alternatively, each stage of the iteration process may be effected by a single equaliser and data regenerator, with the iterative stages being performed by storing the feedback and data decisions between stages or iterations of the turbo detection process.

Advantageously the data sequence may be encoded with an error correction code and the data regenerator means or the plurality of data regenerator means are data decoders which operate to generate the sequence of feed back metrics for the data in accordance with the error correction code.

The channel estimators may operate to adapt a plurality of coefficients of the channel impulse response estimates using a least mean squares algorithm in combination with the error signals and the sequence of data decisions.

The data decision generated by the equaliser means may be soft decision metrics, representative of a likelihood of the detected data symbol being correct. The channel estimator may operate to interpret the soft decision metrics as hard decisions for use in adapting the channel impulse response coefficients.

The equaliser may be an equaliser which operate in accordance with a BCJR algorithm. The BCJR algorithm is disclosed in a publication entitled 'Optimal decoding of linear codes for minimising symbol error rate', by L. R. Bahl, J. Cocke, F. Jelinek and J. Raviv published in the IEEE transactions on information theory, volume IT-20, pages 284 to 287, March 1974. The BCJR algorithm is further elaborated in our co-pending UK patent application No. GB 9804786.3.

According to an aspect of the present invention there is provided a method of detecting data represented as a sequence of received signal samples, the method comprising the steps of estimating an impulse response of a communications channel through which the received signals have passed, using an equaliser means to generate a sequence of data decisions and error signals from the sequence of signal samples in combination with adapted versions of the channel impulse response estimate, the adapted version of the channel impulse response estimate being generated from the data decisions in combination with the error signals, generating a sequence of feed back metrics from said sequence of data decisions, generating a subsequent sequence of data decisions from the feed back metrics in combination with the sequence of signal samples, and estimating the data from the subsequent sequence data decisions, wherein updated versions of the channel impulse response estimate are used to generate each of said subsequent sequence of data decisions.

One embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, wherein;

FIGURE 1 is a schematic block diagram of a radio communications system;

FIGURE 2 is a schematic representation of a time division multiple access frame structure;

FIGURE 3 is a schematic block diagram of a first data detector;

FIGURE 4 is a schematic block diagram of a second data detector;

FIGURE 5 is a schematic block diagram of a third data detector.

An example embodiment of the present invention will be described with reference to a mobile radio communication system, and in particular to a mobile radio communication system which operates in accordance with the global system for mobiles (GSM). The GSM-system is a time division multiple access system in which digital data representative of speech signals is transmitted between mobiles and base stations of the system with the effect that the mobile stations may roam within a radio coverage area provided by the base stations whilst enjoying a facility of data communications via radio signals. The digital data is communicated between the mobile station and the base station using radio signals as illustrated by the communications apparatus shown in Figure 1. In Figure 1 a transmitter 1, which may form part of a base station is shown to communicate radio signals to a receiver 2, which may, for example, be part of a mobile station. Digital data representative of speech is fed to a data formatter 4, via a conductor 6, and is encoded using an error

correction code by a data encoder 8. Encoded digital data signals are fed from the data encoder 8 to the transmitter 10 where the signals are modulated onto a radio frequency carrier signal and transmitted in one of a plurality of time slots in accordance with a time division multiple access system. The radio signals are radiated by a transmit antenna 12, and propagate between the transmit antenna 12 and a receiver antenna 14, via a plurality of paths. The plurality of parts are illustrated in Figure 1 by lines 16, 18, line 18 being reflected from a house 20. Within the receiver 2 the receiver antenna 14 detects the radio signals received via the paths represented as lines 16, 18, and these detected signals are fed to a receiver 22. The receiver 22 operates to down convert and sample the received signals so that the signals are converted into a base band representation of the received radio signals. Thereafter, the digital samples representative of the base band converted radio signals are fed from the receiver 22 to the data detector 24 via a conductor 26. The data detector 24, operates to recover the communicated data from the sampled signals. The data recovered by the data detector 24 is fed to a further processor (not shown) via an output conductor 28.

The radio signals which reach the receive antenna 14, via the paths 16, 18, will be superimposed upon one another as detected by the antenna and receiver 22. Where the difference in the path length between the paths 16, 18, is greater than a symbol period, inter-symbol interference results, requiring an equaliser to be used in the receiver in order for the data to be recovered from the received signals.

An illustration of a time division multiple access frame is illustrated in Figure 2. In Figure 2 the transmission of data on a radio frequency carrier is illustrated by parallel lines 30, 32, which represent the transmission of signals in time going from left to right across the page. The radio frequency carrier is divided into a plurality of time slots represented

as boxes 34. In each of the time slots 34, a burst of radio signals is transmitted. The burst of radio signals is represented in Figure 2 as the rectangle 36, which includes a pre-determined portion of data known to those skilled in the art as a training sequence 38. The time division multiple access system is arranged such that each transmitter may transmit a burst of radio signals 36, in one of the time slots 34, within the time division multiple access frame represented by the lines 30, 32. A mobile radio communication systems such as the GSM system operates with carrier frequencies of 900, 1800 or 1900 MHz. The radio signals transmitted from the transmit antenna 12, to the receive antenna 14, at these frequencies experience both fading and multi-path propagation, as illustrated by the lines 16, 18. As explained the multi-path causes inter-symbol interference in the received signal with the effect that for data to be recovered effectively, the receiver 2, must be provided with an equaliser within the data detector 24.

Equalisers are known to require an estimate of the channel impulse response, through which the received signals have passed and are therefore provided with means to estimate a channel impulse response of the communications channel. To this end, each of the bursts of radio signals 36, is provided with the training sequence 38, which is known to the receiver. At the receiver the data detector 2, is provided with a channel estimator means which operates to convolve a locally generated replica of the known training sequence from which an estimate of the channel impulse response is determined. In order to further improve the integrity of the communicated data regenerated by the data detector 24, that is reduce the number of errors in the communicated data, the data communications system according to GSM-system is known to include to a convolutional code which is effected by the data encoder 8, and encodes the data to be communicated in accordance with the known convolutional code. At the receiver, the data detector is provided with a data decoder

which receives the digital data decisions for the encoded data from the equaliser and operates to recover the data by decoding the encoded data in accordance with the known convolutional code.

As already mentioned, a further detrimental effect known to be experienced by radio signals occurs when there is relative movement between the transmitter and the receiver whilst the burst of radio signals 36, is being transmitted from the transmit antenna 12. As a result of this relative movement, the channel through which the burst of radio signals 36, passes exhibits time dispersion in that the channel impulse response changes with time. As a result, the channel impulse response estimate generated from the received training sequence 38, is only indicative of the communications channel through which the signals have passed, in or around that part of the burst of radio signals 36, where the training sequence 36, was transmitted. In order to mitigate the effects of time dispersion, data detectors are known to be provided with channel estimators which adapt the channel impulse response in accordance with a relative temporal displacement of the received radio signal samples from the temporal position of the training sequence 38.

The turbo equalisation process is a data detection process which is particularly appropriate for receiving and recovering data which have been encoded and transmitted via radio communications channel. This process is described in the above mentioned reference by C. Douillard et al. A data detector which operates in accordance with this turbo detection process is illustrated in Figure 3, where parts also appearing in Figure 1 bear identical numerical designations.

The data detector shown in Figure 3 is comprised of four stages 40, 42, 44, 46. For clarity in providing an explanation of the example embodiment, the iterative nature

of the turbo equalisation process is depicted in a pipeline structure consisting of the cascaded stages 40, 42, 44, 46. Each stage contains an equalising unit 48 and a data regenerator 56. The data regenerator 56, of the example embodiment, is a data decoder which operates to decode the encoded data derived from soft decision estimates generated by the equaliser, to the effect of correcting at least some erroneous estimates of the data that would have resulted from corruption during transmission. Each of the equalising units 48 comprises an equaliser 52 coupled to a channel estimator 54. The base band digital signal samples are fed via conductor 26, to the input of each of the equalisers 52 of the stages 40, 42, 44, 46. Hence the signal samples enter the equalisers 52, for each of the stages of the detection process. Starting from the second stage 42, additional *a priori* feedback metrics generated by the preceding data regenerator 56, are fed into the equaliser 52, of the following stage. The equaliser 52, advances from one time sample to the next and produces soft decision values $SD_i$, or reliabilities for the decoder of the same stage. An error signal $e_i$ is also generated as an intermediate value in the equalisation process for the i-th soft decision value $SD_i$ which is fed to the channel estimator 54, which calculates a new estimate of the channel coefficients $w_i$ from their old values and an update calculated from the error signal $e_i$ in combination with the received signal samples. At each time sample $i$-$1$ a better estimate of the channel impulse response is generated for the present time sample $i$, than that which was used during the equalisation process for the previous time sample $i$-$1$. This better value for the current time sample is then used during equalisation for the next time sample. Thus the channel estimation which requires a symbol decision even for perfect channel estimation is always one time lag behind the real channel. This lag becomes even larger in reality and increases dramatically for small adaptation sizes of the channel impulse response estimate in the case of high vehicle speeds which are required in order to keep noise

amplification acceptable. On the other hand, however, a large adaptation step size provokes unacceptable noise amplification and furthermore also reduces the integrity of the detected data.

As will be appreciated by the cognoscenti, Figure 3 represents one example of a turbo equaliser having four stages. However, the turbo equaliser could be implemented using any number of stages, or as a single stage with iterations of the turbo detection process being effected by storing intermediate data decisions and feed back metrics, for use in a subsequent iteration. The term *a priori* feed back metrics is also known to those skilled in the art by the term 'intrinsic values'.

An example of a channel estimator 54, which operates to adapt the channel impulse response is one which operates in accordance with the known leaky least mean squares algorithm. The least mean squares algorithm operates to increment each coefficient $w_i$ of the channel impulse response estimate by an amount determined by the error signal $e_{t,i}$ received from the equaliser 52, a symbol vector $x_{t,i}$ corresponding to the detected data signals and an adaptation step size $\mu$ according to the algorithm. Derivation of the least mean squares equation from the principle of the steepest descent provides an update equation for the tap coefficients $w_i$ with the elements being multiplied by each other element. The well known leaky least mean squares algorithm is described in accordance with equation (1), where $t$ denotes time, the symbol vector $x_t$ corresponds to hard decision values interpreted from the soft decision metrics generated by the equaliser 52, and $\mu$ is the adaptation step size.

$$\bar{w}_{t,i} = L\bar{w}_{t,i-1} + \mu e_{t,i-1}\bar{x}_{t,i-1} \qquad (1)$$

Having regard to equation 1, it can be realised that fast adaptation required to track substantially changes in the

channel impulse response introduces severe noise amplification as is known to those acquainted with adaptive filters. The noise amplification is greater where more coefficients $w_i$ are introduced in the channel impulse response and adapted in accordance with this algorithm. This effect becomes devastating close to a theoretical stability bound which limits the adaptation step size roughly to the inverse of the number of adapted coefficients. This is especially true if tentative symbol decisions are made for adaptation purposes. Thus as will be appreciated from the data detector 24, shown in Figure 3, one important factor in maintaining the integrity of the detected data, is an accurate estimate of the channel impulse response. In the case of time dispersive channels, the channel estimator must adapt the channel impulse response in order to maintain the integrity of the detected data. However a limitation on the architecture shown in Figure 3 of the data detector 24, is that the updated estimate of the channel impulse response is always one data symbol sample behind the one currently being detected.

A data detector 24′, which exemplifies the present invention is shown in Figure 4. In Figure 4, the iterative structure of the turbo equalisation process is once again depicted in a pipeline architecture consisting of a cascade of stages 40, 42, 44, 46. Each stage corresponds substantially to the stages shown in Figure 3 where an equaliser unit 48′, is connected to an associated data regenerator 56, with the equalisation unit 48′ comprising an equaliser 52′ and a channel estimator 54′. As with the data detector 24, shown in Figure 3, each of the digital samples of the radio signal is fed via a conductor 26, to each input of the equalisers 52′, as will be the case for all iterations loops. Starting from the second loop additional *a priori* feedback metrics are generated by the preceding decoder 56, by the preceding stage of the algorithm and are fed into the following stage to the equaliser 52′. The equaliser advances from one time sample to

the next and produces a sequence of soft decision metrics $SD_i$, for the data regenerator 56, of the same stage. The error signal $e_i$ is generated as an intermediate value in the equalisation process and fed to the channel estimator 54, as herein before described for the data detector 24, shown in Figure 3. As with the channel estimator 54, shown in Figure 3, the channel estimator 54', calculates a new estimate of each of the plurality of coefficients $w_i$ of the channel impulse response for all time samples from their previous value to an updated value calculated in accordance with equation (1). At each stage, the channel estimator 54', generates a better estimate for all time samples of the received signal sample than the one actually used during the equalisation for the current stage. However unlike the data detector 24 shown in Figure 3, the updated channel impulse response coefficients are fed to the equaliser 52' in the subsequent stage 42, 44, 46, and used in the equaliser 52' of the subsequent stage. Thus the channel estimation is always generated from the previous one of the stages and used in the next stage to equalise the data. Unlike the data detector 24, shown in Figure 3, the data detector 24' shown in Figure 4 is able to provide an updated version of the channel impulse response to the subsequent stage in temporal correspondence with each detected data symbol of the current stage. That is to say, the channel impulse response estimate is already updated and is used in the subsequent estimation of the data symbol in correspondence with the temporal position of that data symbol with the adaptation of the channel impulse response which is effected to reflect the temporal change in the channel impulse response. Thus there is no time delay between the channel estimation adaptation and the equalisation of the corresponding data symbol and therefore no lag between adaptation and equalisation. Thus no lag occurs, so that smaller adaptation step sizes can be used in the case of high vehicle speeds desired in order to reduce a noise amplification.

In the first stage 40, of the data detector 24', no channel estimate is provided from a previous one of the stages, so that a rather large adaptation step size is required from one signal sample to the next in order to facilitate an acceptable rate of update of the channel impulse response coefficients to track the corresponding effects of time dispersion. In subsequent stages 42, 44, 46, the equaliser 52, is provided with an estimate adapted from the previous stage as from the second stage 42. As such, the adaptation process can be tuned to the effect that convergence of the algorithm can be accurately determined independently of the requirement to track the changes in the impulse response. If a number of stages, or correspondingly a number of iteration loops, of the turbo equalisation process is to be kept low, fast convergence of the adaptation algorithm is preferred with an adaptation size which can be decreased from one stage to the next to ensure fast convergence and an acceptable final noise amplification. Thus, the adaptation process effected by the channel estimators 54' in the data detector 24, shown in Figure 4, is now described in accordance with equation (2), where once again $x_{t,i-1}$ represents a symbol vector of hard decisions interpreted from the soft decision output $SD_i$, μ is the adaptation step size and $w_i$ are the coefficients of the channel impulse response with $t$ denoting the time sample.

$$\bar{w}_{t,i} = L_i \bar{w}_{t,i-1} + L_t \bar{w}_{t-1,i} + \mu_i e_{t,i-1} \bar{x}_{t,i-1} + \mu_t e_{t-1,i} \bar{x}_{t-1,i} \qquad (2)$$

As will be appreciated the data regenerators 56, are operating in accordance with a decoding algorithm so that with the present example embodiment of the invention data which has been encoded is decoded by the data regenerators 56, in order to provide a coding gain to further improve the integrity of the detected data. In order to minimise the delay in generating the soft decision metrics and error signals $e_{t,i-1}$ by the equaliser 52, the equalisers 52' preferably operate in accordance with the BCJR equalisation

algorithm which is known to those skilled in the art and is described in the above mentioned published article entitled 'Optimum decoding of linear codes for minimising symbol error rate by L.A. Bahl et al', and in the applicants co-pending UK patent application serial number GB 9804786.3, as previously mentioned. In the case of the BCJR algorithm, the equaliser may be divided into a forward equalisation stage and a backward equalisation stage which are subsequently combined in an equaliser combiner means. Such an algorithm affords an opportunity to adapt the channel impulse response estimate separately with respect to the forward equalisation stage and the backward equalisation stage. A data detector 24'' which operates in accordance with the BCJR algorithm and which adapts the channel impulse response estimate separately for both forward and backward stages is shown in Figure 5 where parts also appearing in Figures 1, 3 and 4 bear identical numerical designation. In Figure 5 two example stages 40, 42, are shown to include data decoders 56, and an equalising unit 48''. Within the equalising unit 48'' is a forward equaliser 60, which operates to generate soft decision metrics moving forward in time with respect to the received sequence of signal samples and a backward equaliser 62, which operates to generate decision metrics moving backwards in time between the signal samples. The forward and backward decision metrics are fed to an equaliser combiner 64, which operates to generate the soft decision metrics fed to the data regenerator 56. As the forward and backward equalisation steps are separate, the channel impulse response coefficients are adapted separately by channel estimate adapters 66 and 68 respectively. In this case, the backward channel impulse response adapter 68 provides the channel impulse response estimate for use in the forward equaliser 60 which operates to effect forward recursion of the BCJR algorithm, in the next stage. Thus, the data detector 24'' shown in Figure 5 provides a means for doubling the adaptation steps by considering the forward and the backward recursions as separate adaptation steps. Hence the equaliser in this case

consists of a forward recursion block 60, and a backward recursion block 62. The forward recursion updates the results of the backward recursion of the previous stage as the case may be, and the following backward recursion updates these results once more as is illustrated in Figure 5.

As will be appreciated by those skilled in the art various modifications may be made to the aforementioned example embodiment without departing from the scope of the present invention. For example the data regenerator may operate to provide some other means for improving the integrity of the received signal and for providing the *a priori* feed back metrics for the equaliser. Furthermore various equalisation algorithms could be used for the equalisers. The present invention also finds application in various other multiple access techniques which require data represented as radio communication signals to be detected in the presence of multi-path propagation effects and time dispersion.

Claims:

1. A data detector (24) which operates to generate an estimate of a data sequence from a sequence of received signal samples, said data detector comprising
- a channel estimator means (54) which operates to generate an estimate of an impulse response of a communications channel through which the received signals have passed,
- an equaliser means (48) coupled to said channel estimator means (54) which operates to generate a sequence of data decisions ($SD_i$) and error signals ($e_i$) from said sequence of signal samples in combination with adapted versions of said channel impulse response estimate, said channel impulse response estimate being adapted by said estimator means (54) in accordance with said error signals and said data decisions, and
- a data regenerator means (56) which operates to process said sequence of data decisions ($SD_i$) and to generate therefrom a sequence of feed back metrics which are fed to said equaliser, said equaliser further operating to generate a subsequent sequence of data decisions ($SD_i$) from said feed back metrics in combination with said sequence of signal samples, which subsequent data decisions are fed to said data regenerator (56) which operates to generate said estimate of said data from said subsequent data decisions, wherein each of said updated versions of said channel impulse response estimate is used to generate said subsequent sequence of data decisions.

2. A data detector as claimed in Claim 1, wherein the adapted versions of said channel impulse response estimate are arranged in a temporal correspondence with the sequence of received signal samples from which said equaliser means determines said subsequent sequence of data decisions, whereby a delay between generating each of said subsequent sequence of data decision and updating said channel impulse response estimate is substantially obviated.

3. A data detector as claimed in Claim 1 or 2, wherein said data regenerator means (56) operates to generate a plurality of sequences of feed back metrics, fed to said equaliser means (48) which generates a corresponding plurality of sequences of data decisions ($SD_i$) and error signals ($e_i$), said plurality of sequences of data decisions ($SD_i$) being used by said data regenerator (56) to form said plurality of feed back metrics and said error signals ($e_i$) being used to adapt said channel impulse response estimate for each of said plurality of sequences of data decisions generated by said equaliser, each of which adapted versions of the channel impulse response estimate being used in a subsequent iteration to form a subsequent one of said sequences of data decisions($SD_i$).

4. A data detector as claimed in Claim 3, wherein said equaliser means (48) is a plurality of equaliser means, said channel estimator (54) is a plurality of channel estimator means and said data regenerator means (56) is a plurality of data regenerator means, said plurality of equaliser means, channel estimator means and data regenerator means being coupled together to form a corresponding plurality of stages (40, 42, 44, 46), each of which stages operating to generate one of said plurality of sequences of data decisions, one of said plurality of feed back metrics, and one of said versions of said channel impulse response estimates, the version of the channel impulse response estimate from one stage (40, 42, 44) being fed to the channel impulse response estimate of a subsequent stage (42, 44, 46).

5. A data detector (24) as claimed in any preceding claim, wherein said data sequence has been encoded with an error correction code, and said data regenerator means (56) or said plurality of data regenerator means (56) are data decoders which operate to generate said sequence of feed back metrics

or said data estimate by decoding said sequence of data decisions in accordance with said error correction code.

6. A data detector as claimed in any preceding Claim, wherein the or each of said channel estimators operates to adapt each of a plurality of coefficients of said channel impulse response estimate using a least mean squares algorithm in combination with said error signals and said sequence of data decision.

7. A data detector as claimed in any preceding claim, wherein an amount by which said channel impulse response estimate is adapted is different in dependence upon the stage or iteration being performed by said equaliser means.

8. A data detector as claimed in any preceding Claim, wherein said sequences of data decisions are sequences of soft decision metrics.

9. A data detector as claimed in any preceding Claim, wherein said equaliser is a BCJR equaliser, comprising a forward (60), a reverse (62) and a combine means (64), and said channel estimate is adapted by said channel estimator means (66, 68) separately using error signals provided by said forward and said reverse means.

10. A radio communications receiver (2) comprising means to detect radio signals (14, 22) and to generate there from a sequence of signal samples, and a data detector (24) as claimed in any preceding claim.

11. A method of detecting data represented as a sequence of received signal samples, said method comprising the steps of
- estimating an impulse response of a communications channel through which the received signals have passed;
- using an equaliser means to generate a sequence of data decisions ($SD_i$) and error signals ($e_i$) from said sequence of

signal samples in combination with said channel impulse response estimate;
- adapting said channel impulse response estimate in accordance with said error signals ($e_i$);
- generating a sequence of feed back metrics from said sequence of data decisions ($SD_i$);
- generating a subsequent sequence of data decisions ($SD_i$) from said feed back metrics in combination with said sequence of signal samples; and
- estimating said data from said subsequent sequence of data decisions, wherein updated versions of said channel impulse response estimate are used to generate each of said subsequent sequence of data decisions.

12. A method of detecting data as claimed in Claim 11, wherein the versions of the adapted channel impulse response are arranged in temporal correspondence with the signal samples from which the data decisions ($SD_i$) are generated.

13. A method of detecting data as claimed in Claims 11 or 12, and further including the steps of;
- generating a plurality of sequences of data decisions ($SD_i$) and error signals ($e_i$), from said sequence of signal samples in combination with one of a plurality of sequences feed back metrics and one of a plurality of adapted versions of said channel impulse response estimate;
- for each of said sequences of data decisions ($SD_i$) generating one of said plurality of sequences of feedback metrics, which is used to generate a subsequent one of said data decisions ($SD_i$) and error signals ($e_i$);
- for each of said plurality of sequences of data decisions ($SD_i$) adapting said channel impulse response estimate, in accordance with the sequence of data decisions ($SD_i$) and a corresponding one of said adapted versions of said channel impulse response, thereby providing each of said plurality of adapted versions of said channel impulse response estimate, wherein each adapted version of said channel impulse response

is used by the equaliser means to generate a corresponding subsequent one of the plurality of sequences of data decisions ($SD_i$).

14. A method of detecting data as claimed in Claim 11, 12 or 13, wherein the data has been encoded in accordance with an error correction code and the step of generating said plurality of sequences of feed back metrics and regenerating said data is effected by decoding said sequence of data decisions in accordance with said error correction code.

15. A method of detecting data as claimed in any of claims 11 to 14, wherein each of a plurality of coefficients ($w_i$) of said channel impulse response estimates are adapted using a least mean squares algorithm in combination with said error signals ($e_i$) and said sequence of data decisions.

16. A method of detecting data as claimed in any of claims 11 to 15, wherein said channel impulse response estimate is adapted differently in dependence upon which of the plurality of sequences of data decisions is being generated by said equaliser.

17. A method of detecting data as claimed in any of claims Claim 11 to 16, wherein said data decisions are soft decision metrics.

18. A data detector as herein before described with reference to the accompanying drawings.

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| **Application No:** | GB 9819244.6 | **Examiner:** | Stephen Brown |
| **Claims searched:** | 1-18 | **Date of search:** | 16 March 1999 |

## Patents Act 1977
## Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): H4P (PRE)

Int Cl (Ed.6): H04L: 25/02, 25/03.

Other: Online : WPI, EPODOC, JAPIO

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | Relevant to claims |
|---|---|---|
| A | GB 2 247 812 A (Motorola) | - |
| A | EP 0 804 007 A2 (Oki) | - |
| A | EP 0 682 420 A1 (Alcatel) | - |
| A | US 5 533 063 (University of California) | - |

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